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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFAMRL-TR-80-83	2. GOVT ACCESSION NO. AD-A094 576	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EFFECT OF BODY SUPINATION ANGLE ON SUBJECTIVE RESPONSE TO WHOLE-BODY VIBRATION		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Cariold B. Harrah Richard W. Shoenberger		8. CONTRACT OR GRANT NUMBER(s) F33615-79-C-0509
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, Ohio 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62202F; 7231-10-01
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE January 1981
		13. NUMBER OF PAGES 7
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Reprinted from Aviation, Space, and Environmental Medicine, January, 1981.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Three experiments were conducted to evaluate the subjective symptomatology associated with various combinations of supination angle and vibration spectral composition. Sinusoidal, sum-of-sine, and random vibration were used in the first, second and third experiments, respectively. All exposure periods were 40's and the supination angle was varied from 13-65°. Subjective response was evaluated by means of a physical symptom survey incorporating a discomfort rating scale. For all three experiments, the results indicated a primary effect of supination angle was to shift the vibration-induced (continued)		

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Effect of body supination angle on subjective response to whole-body vibration

CARIOLD B. HARRAH and RICHARD W. SHOENBERGER

Air Force Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433

HARRAH, C. B., and R. W. SHOENBERGER. *Effect of body supination angle on subjective response to whole-body vibration.* Aviat. Space Environ. Med. 52(1):28-32, 1981.

Three experiments were conducted to evaluate the subjective symptomatology associated with various combinations of supination angle and vibration spectral composition. Sinusoidal, sum-of-sine, and random vibration were used in the first, second, and third experiments, respectively. All exposure periods were 40 s and the supination angle was varied from 13-65°. Subjective response was evaluated by means of a physical symptom survey incorporating a discomfort rating scale. For all three experiments, the results indicated a primary effect of supination angle was to shift the vibration-induced sensations across body regions. Small angles (nearly seated upright) were most often associated with stomach, abdomen, and head discomfort; large angles were most often associated with upper back, neck, and sacral discomfort. With respect to the calculated total-body response, results indicated a preference for the 30° supination angle for both complex vibration spectrums used and for all three sinusoidal frequencies. This finding suggests the existence of an optimal supination angle for comfort under vibration.

RECENT TECHNOLOGICAL advances in the aerospace industry have resulted in higher-performance fighter aircraft which are, in turn, creating requirements for improved methods to protect the pilot from sustained G loading. At the present time, the most promising approach, utilized in the High Acceleration Cockpit (HAC) design concept, is to elevate the body of the pilot relative to his head. The effect of this change in configuration is to assist in maintaining eye-level blood pressure, reduce blood pooling in the extremeties, and reduce heart rate.

Unfortunately, the effects produced by reclining the body in this manner may not all be beneficial. One area in which such changes may cause additional problems is human response to mechanical vibration. An increased supination angle, characterized by the body being more reclined, is expected to result in several changes in a pilot's biodynamic and psychological response in a vibration environment. In particular, the more or less horizontal body configuration will modify the body's biodynamic response to vertical vibration inputs (the dominant direction of vibration in most fighter aircraft) and produce a response somewhere between what is seen for a conventional, essentially upright seating position and that produced by the semi-supine configuration used in space flight. Additionally, maintaining a vertical head position while the supination angle is increased will cause a more direct coupling of the pilot's head to the aircraft headrest, which is expected to increase both the discomfort and the visual interference produced by vibration.

There is a considerable body of literature related to the biodynamic, psychophysical, and performance effects of vibration when the subject is seated upright, as the pilot is in a conventionally configured aircraft (3). There are also several studies of human response to vibration in a semi-supine position (1,2,4-6), representative of a spacecraft configuration, i.e. with the upper body nearly horizontal and the lower legs elevated and parallel to the upper body. However data are lacking on human vibration response for intermediate supination angles in an HAC-type configuration.

In response to this need, a series of studies has been conducted to evaluate the effect of supination angle on human comfort and performance during vibration. The first of these studies consisted of three experiments designed to evaluate the subjective symptomatology associated with various combinations of supination angle

This research was conducted by personnel of the Air Force Aerospace Medical Research Laboratory. Reprints of this paper are identified as AFAMRL-TR-80-83. The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

Instrumentation and operation of the vibration machine, and production, analysis, and calibration of the vibration stimuli were done by personnel of the University of Dayton Research Institute under Contract F33615-79-C-0509.

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and vibration spectral composition. Sinusoidal, sum-of-sines, and random vibration were used in the first, second, and third experiments, respectively. In all three experiments, subjective response was evaluated by means of a physical symptom survey incorporating a discomfort rating scale.

MATERIALS AND METHODS

Subjects: The subjects were male Air Force military personnel who were physically qualified volunteer members of a vibration panel. They received incentive pay for participation in vibration experiments. Six subjects participated in Experiment I, seven subjects in Experiment II, and 11 subjects in Experiment III.

Apparatus: Whole-body vibration was produced by the AFAMRL six-degrees-of-freedom motion device (SIXMODE). The SIXMODE is an electro-hydraulic device capable of motion in any of six degrees-of-freedom. The vibration seat was rigidly constructed of steel and aluminum, and bolted directly to the SIXMODE vibration platform (Fig. 1). It provided head, arm, leg, and foot support, and was articulated to allow easy adjustment of the back angle and headrest angle. The back angle was varied 13-65° from the vertical, and the headrest angle was changed concomitantly so that it maintained a vertical orientation regardless of the back angle. The subject was secured to the vibration seat by a lap belt and shoulder harness, and was required to keep his head against the headrest during the vibration runs. The seat pan and back were unpadded and transmitted the vibration directly to the supporting surfaces of the body, and the headrest was fitted with a 0.64 cm (0.25 in) firm rubber pad, which gave only minimal cushioning.

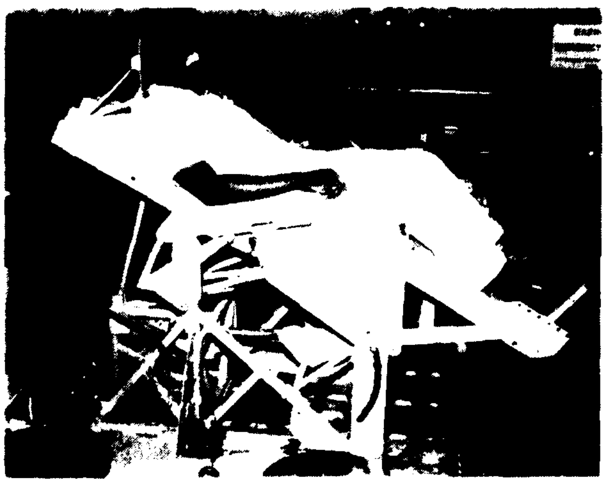

Fig. 1. View of articulated seat at 65° back angle.

Experimental Conditions: The major independent variables in these experiments were the supination angle of the seatback and the spectral composition of the vibration. In all three experiments, five different supination angles were tested: 13°, 18°, 30°, 45°, and 65° of reclination of the upper body's Z axis from the vertical position. In the first experiment, the vibration inputs were single sinusoidal frequencies of 2, 5, and 15 Hz, at 0.3 G R.M.S. A quasi-random vibration input was synthesized in the second experiment, by combining five sinusoids: 2, 3.3, 5, 7, and 10 Hz. Two intensities were used, 0.15 G R.M.S. and 0.30 G R.M.S., with an essentially flat distribution of power over the five frequency components. In the third experiment, a random vibration input was generated from a filtered random signal. The spectrum was approximately flat, with a band width from 2-10 Hz. Intensities of 0.15 G R.M.S. and 0.25 G R.M.S. were used. Table I summarizes the intensity, spectral, and duration parameters for each experiment. In all three experiments, the direction of the vibration was vertical.

Procedure: Basically, an experimental session involved exposing a subject to each of the vibration conditions in a given experiment at each of the five angles. There were 15 combinations of the back angle and vibration input in the first experiment and 10 combinations in each of the second and third experiments. For each experiment, the experimental conditions were administered to each subject in a different random order.

For each experimental condition, the vibration exposure lasted for 40 s, a sufficient time to form a subjective impression of the vibration severity at various locations on the body. At the end of each 40-s exposure, the subject was required to evaluate the subjective symptomatology associated with a particular combination of supination angle and vibration input, using a physical symptom survey. The survey consisted of a drawing of the body showing 34 body areas (Fig. 2) and a response sheet (Fig. 3) which had a discomfort rating scale corresponding to each of the 34 areas. The subject was instructed to place a mark on each of the scales corres-

TABLE I. VIBRATION INPUT PARAMETERS

PARAMETER / EXPERIMENT	INTENSITY	SPECTRUM	DURATION
EXP NO 1	0.30 G R M S	SINUSOIDAL 2, 5, 15 Hz	40s
EXP NO 2	0.30 G R M S and 0.15 G R M S	SUM-OF-SINE 2, 3.3, 5, 7, 10 Hz	40s
EXP NO 3	0.25 G R M S and 0.15 G R M S	RANDOM BW 2-10 HZ	40s

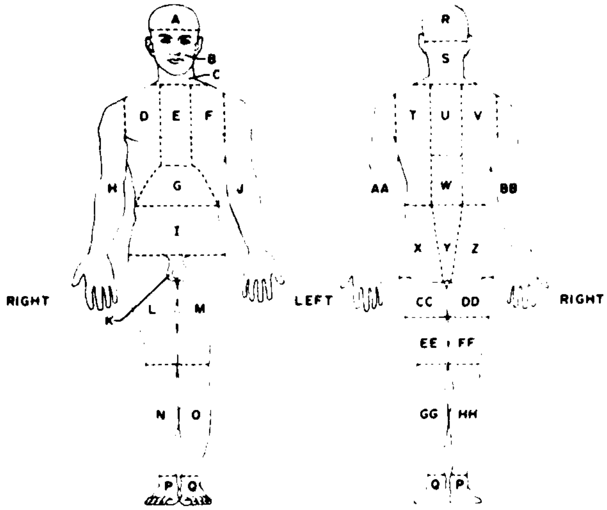

Fig. 2. Body areas for physical symptom survey.

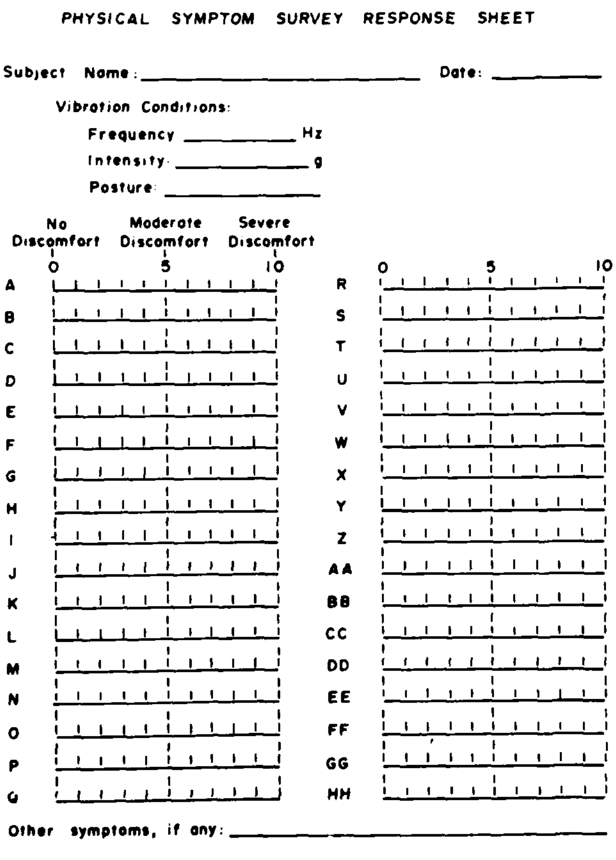

Fig. 3. Response sheet showing rating scales for each body area.

ponding to the degree of discomfort experienced for each body area. The response sheet also provided space for the subject to describe any symptoms that he felt could not be expressed via the rating scale.

As part of the data analysis process, a single overall subjective response for the body was calculated from the individual responses for each of the 34 body areas. The computational procedure involved a simple averaging of those individual area responses which had essentially non-zero response. That is, those areas showing *no* sensitivity to either position or frequency were excluded from the overall response. These included the lower legs and feet, arms and hands, and testicles.

RESULTS AND DISCUSSION

Results for Experiment I and for the higher intensity for Experiments II and III are graphically presented in Fig. 4-6 to allow comparison of the responses to the

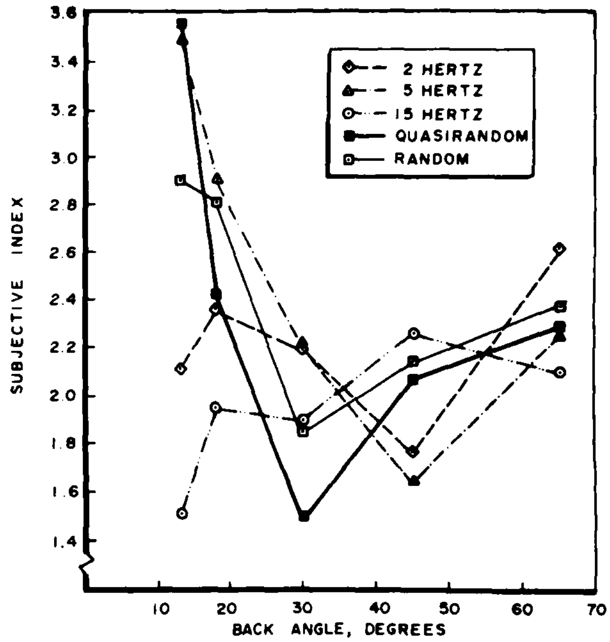

Fig. 4. Subjective response for the back of the head, as a function of seatback angle and type of vibration.

various types of vibration input. The results shown in the figures are for those three body areas where, for all three experiments, the subjective rating was significantly affected by the back angle as indicated by analyses of variance performed for each body area. The three areas are: back of head, back of neck, and shoulders and upper spinal region. The results for each of the three experiments will now be described. Not all responses described are reflected in the figures since, within any of the three experiments, the responses may involve areas other than the three common areas in Fig. 4-6.

The results of the first experiment demonstrated a frequency effect on the regional subjective response in addition to supination angle effects. For the 2 Hz vibration, discomfort at the back of the head was dominant at all back angles except 65°, where sacral region discomfort was the most pronounced effect. For the upper back regions, subjective response appeared to be minimal at 30° supination angle with maximum response occuring at 65°. For the 5 Hz exposure, the primary sensations were discomfort to the back of the head (head banging), stomach discomfort, and lower abdominal discomfort at the nearly upright positions of 13° and 18°. These subjective intensities were less at back angles

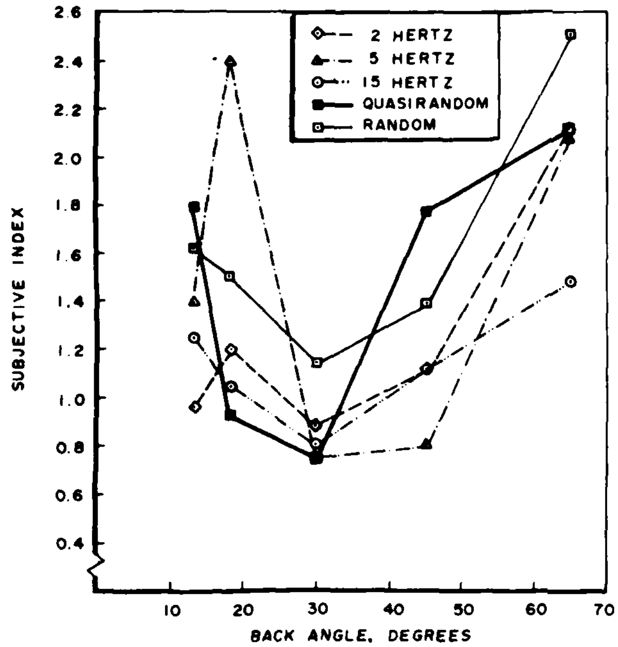

Fig. 5. Subjective response for the back of the neck, as a function of seatback angle and type of vibration.

of 30° and 45° with the lumbar/sacral regional response becoming more important. In a manner similar to the 2 Hz case, subjective intensity at the upper back region was maximum at 65°, appeared to be minimal at 30°, and increased for the 18° back angle. For the 15 Hz exposure, the most pronounced subjective effects were associated with vibration of the facial area and the back of the head. Although not as pronounced, the intensity ratings

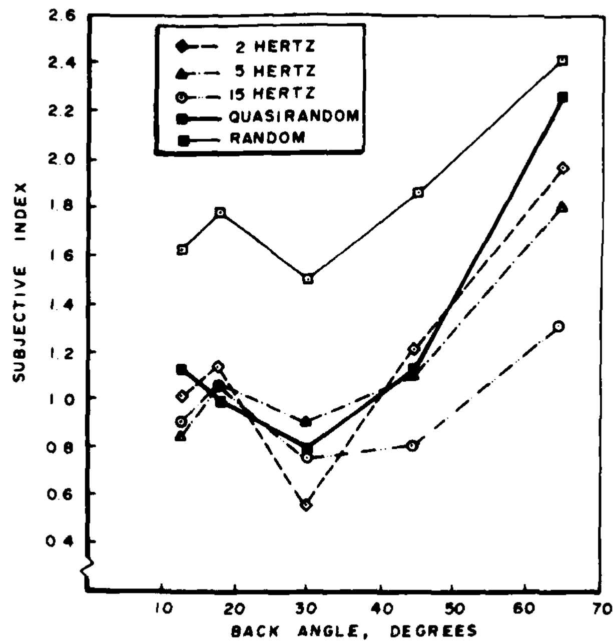

Fig. 6. Subjective response for the back of the shoulders and upper spinal region, as a function of seatback angle and type of vibration.

in the upper back region were greatest for the 65° back angle and minimal in the 30° position.

In the second experiment (quasi-random vibration), the results indicated that the strongest subjective responses for the nearly upright positions of 13° and 18° were for the stomach, abdomen, and back of the head and neck. These responses were smaller at the 30° back angle and generally increased again at the 45° and 65° positions. This was especially true for the back of the neck. The response for the back of the shoulders and upper spinal region was maximal at 65° reclination and generally became smaller with smaller back angles. With respect to vibration intensity, 0.3 G R.M.S. elicited a higher subjective response than 0.15 G R.M.S. at all back angles for practically all body regions. However, for a given body area, intensity did not vary the shape of the response curves formed by plotting subjective intensity as a function of back angle.

In the third experiment (random vibration), analysis of the data showed that response patterns for the random vibration were similar to the sum-of-sine case, including the intensity effects mentioned above. In some body areas, however, the subjective index of intensity was somewhat higher for the random vibration. This higher sensitivity to random vibration, relative to sum-of sine, is reflected in Fig. 4-6. Fig. 7, which shows

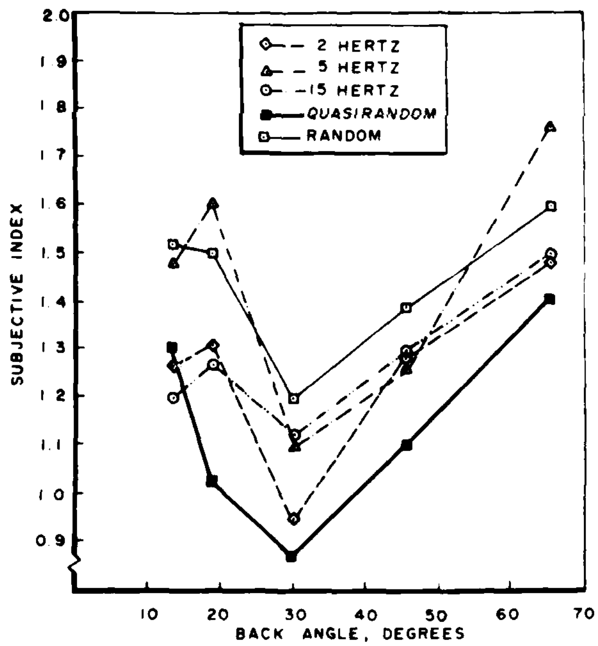

Fig. 7. Calculated total body response, as a function of seatback angle and type of vibration.

the calculated total body response as a function of supination angle, also indicates a greater sensitivity to random vibration. This result may have been produced by the higher crest factors characteristic of random inputs.

Generally, for all three experiments, the results indicated a primary effect of supination angle was to shift the vibration-induced sensations across the body regions. Small angles (nearly seated upright) were most often

associated with stomach, abdomen, and head discomfort; large angles were most often associated with upper back, neck, and sacral discomfort. With respect to the calculated total body response (Fig. 7), results indicated a preference for the 30° supination angle for both complex vibration spectrums used and for all three sinusoidal frequencies. This finding suggests the existence of an optimal supination angle for comfort under vibration and indicates a need for extension of this type of experimentation to longer duration exposures characteristic of low-level, high-speed flight.

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